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(54) **RAILROAD SIGNALING AND COMMUNICATION SYSTEM USING A FAIL-SAFE VOLTAGE SENSOR TO VERIFY TRACKSIDE CONDITIONS IN SAFETY-CRITICAL RAILROAD APPLICATIONS**

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(52) **U.S. Cl.**
CPC ***B61L 27/0088*** (2013.01)

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USPC ..... 701/19; 702/64; 340/540, 679, 988; 246/3, 28 R, 34 R, 122 R, 167 R, 169 A, 246/186, 187 A, 187 B, 220
See application file for complete search history.

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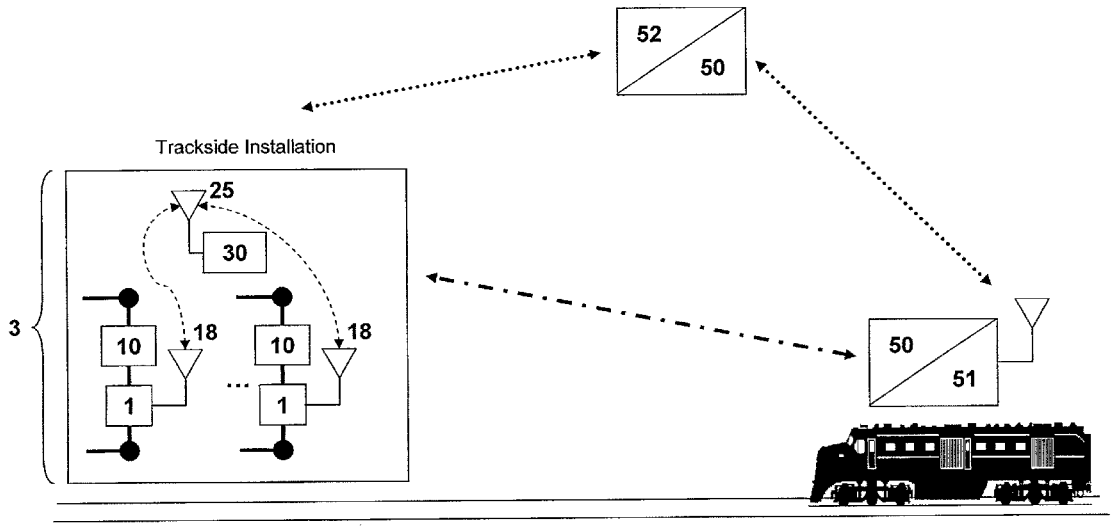
(57) **ABSTRACT**

A method and system for verifying trackside conditions in safety critical railroad applications by reporting the status of trackside signals and switches to a remote train control system. The system comprises at least one sensor for providing trackside conditions electrically connected to a circuit for providing trackside conditions to a railroad, said sensor being powered by voltage applied to the circuit such that the sensor is energized only when said electrical component is engaged. The system and method further comprises a method and system which is failsafe and which enables the control system to independently verify signals from each sensor.

9 Claims, 5 Drawing Sheets



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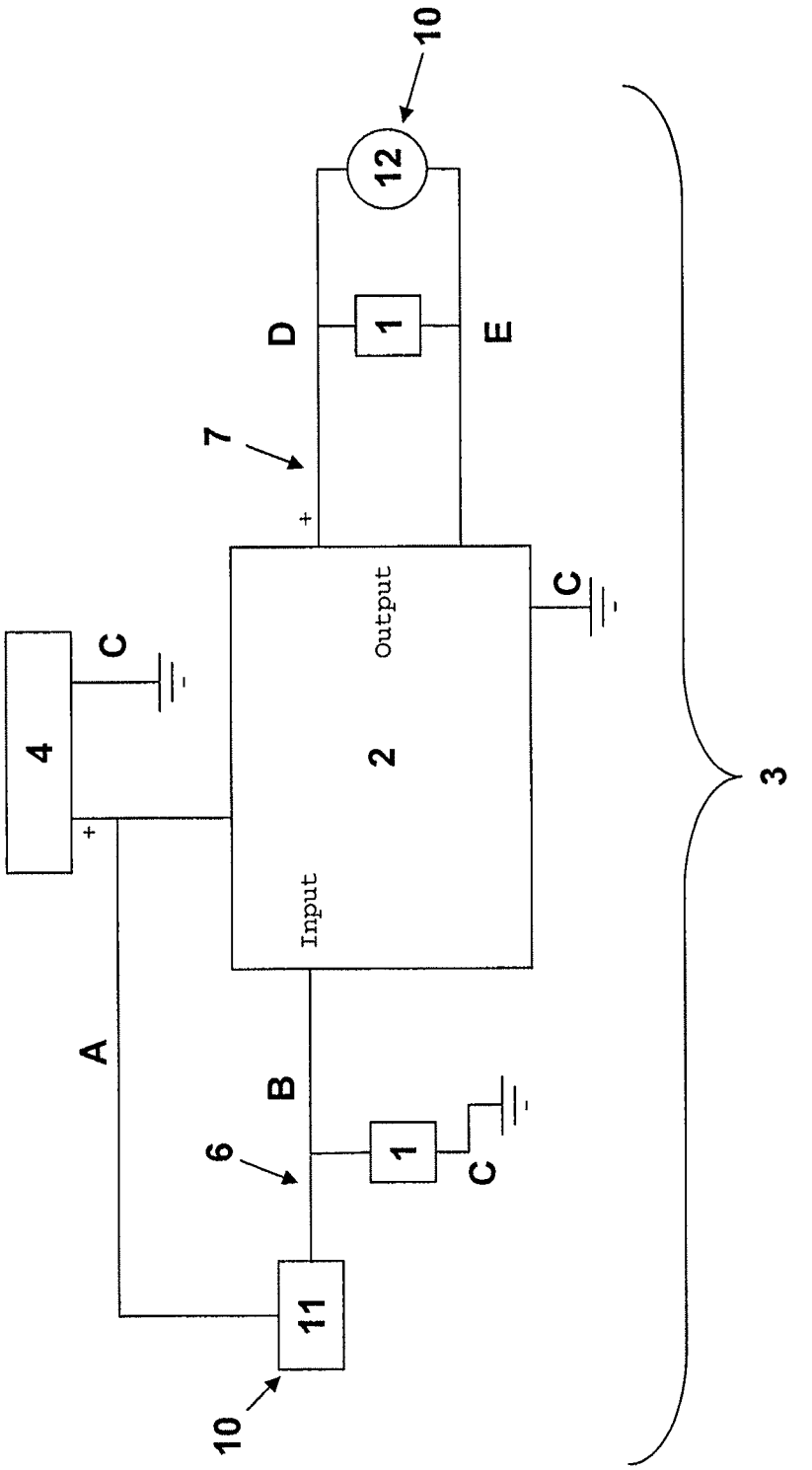


Figure 1

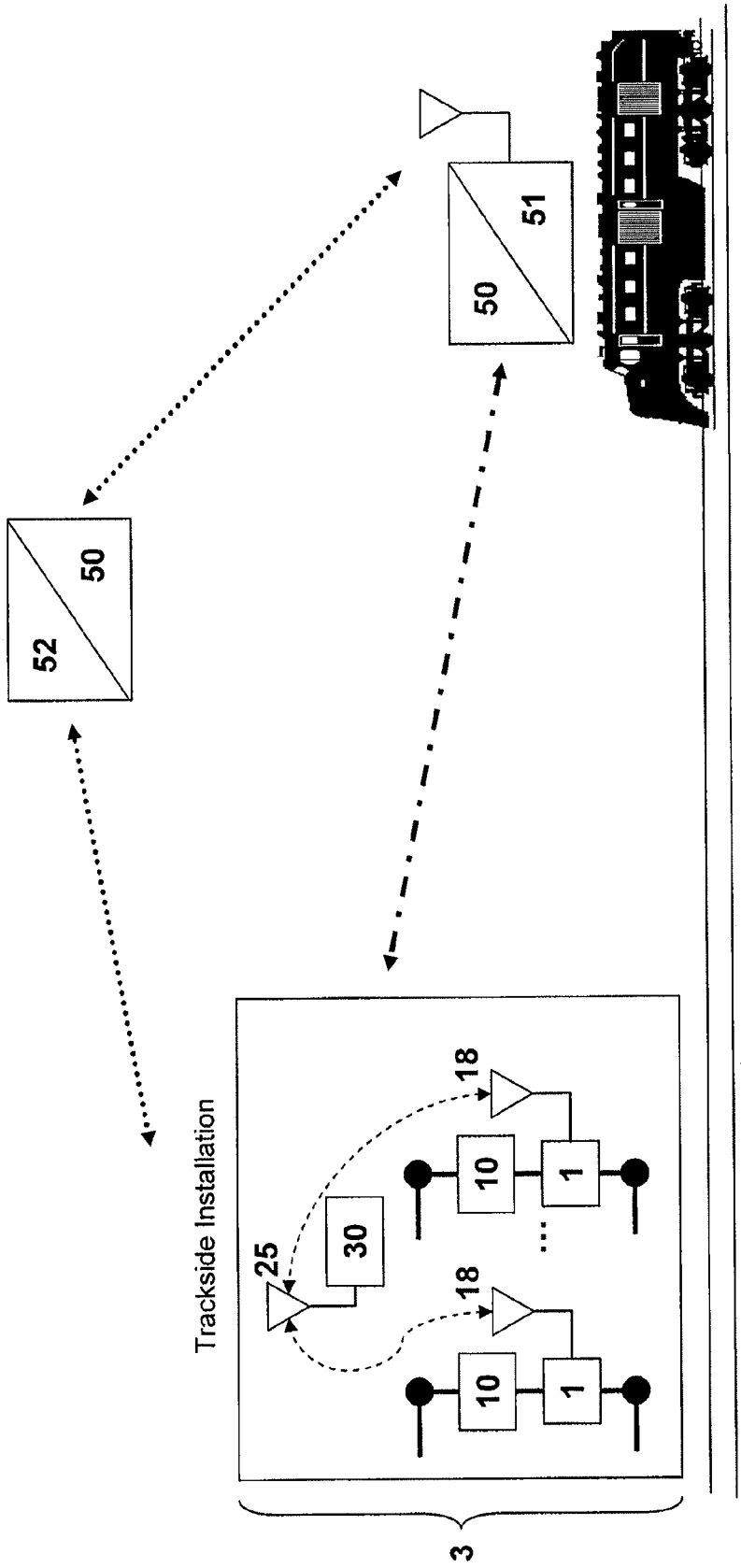


Figure 2

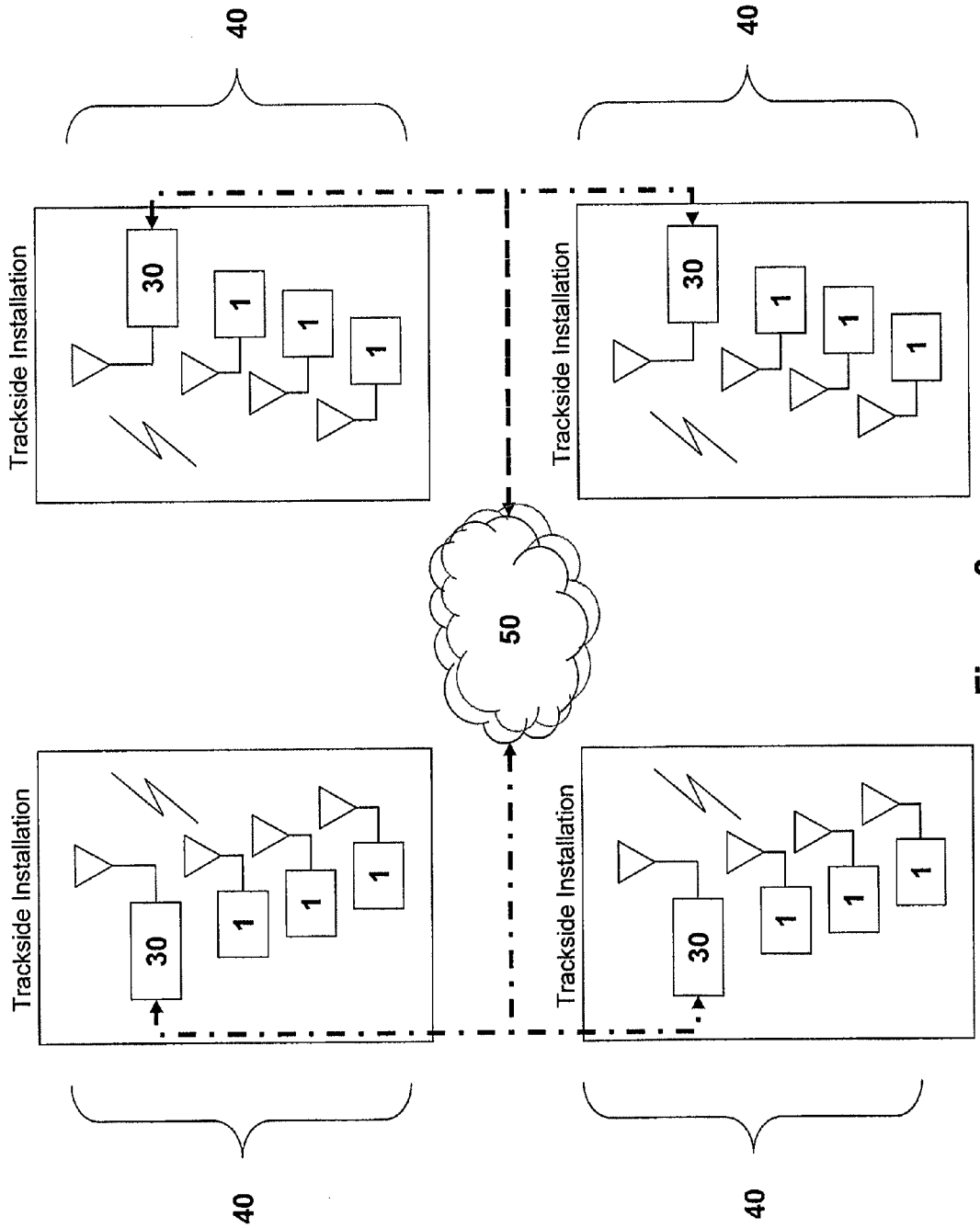

40
40
Trackside Installation
30
1
1
1
Trackside Installation
30
1
1
1
50
Trackside Installation
30
1
1
1
Trackside Installation
30
1
1
1
40
40

Figure 3

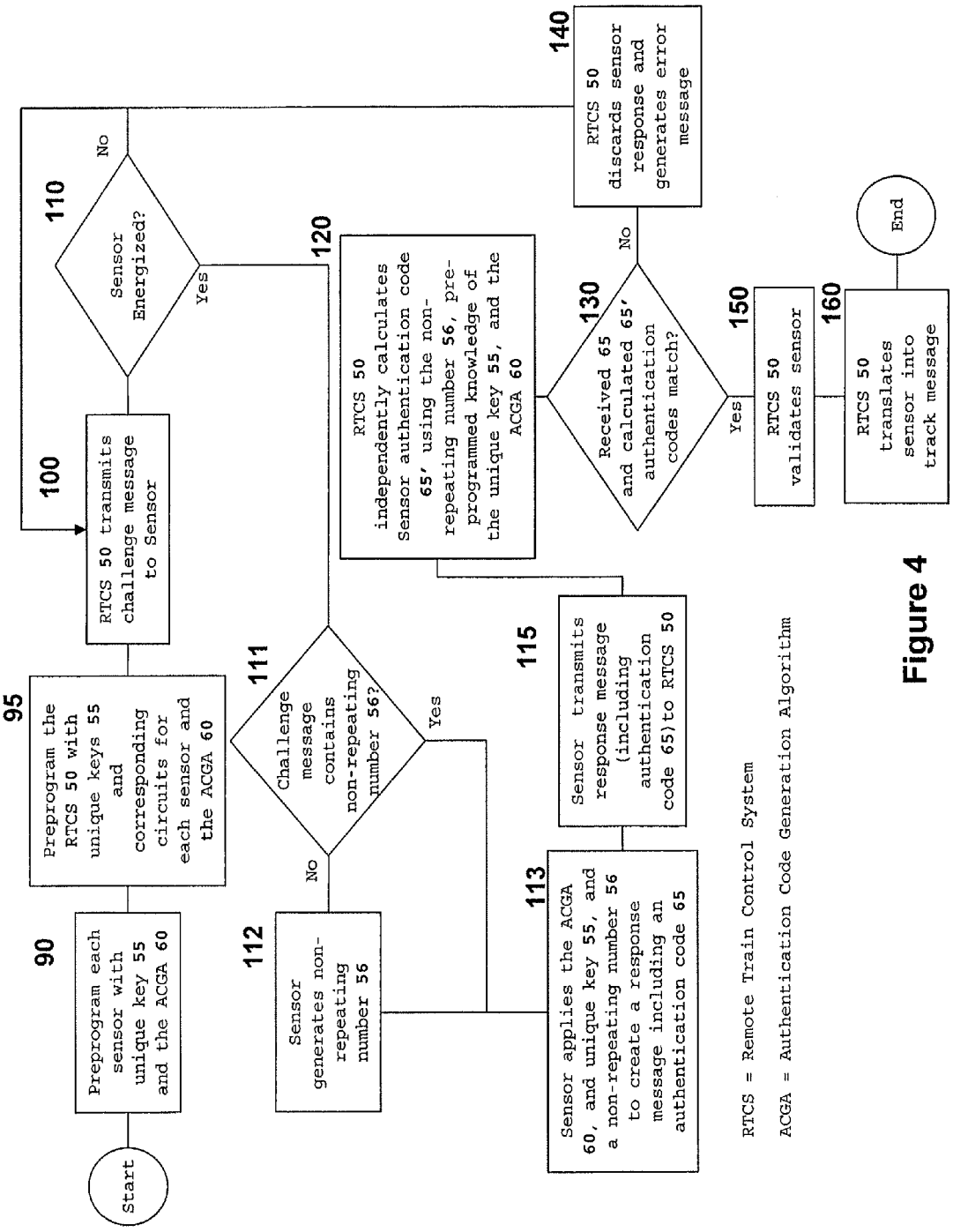
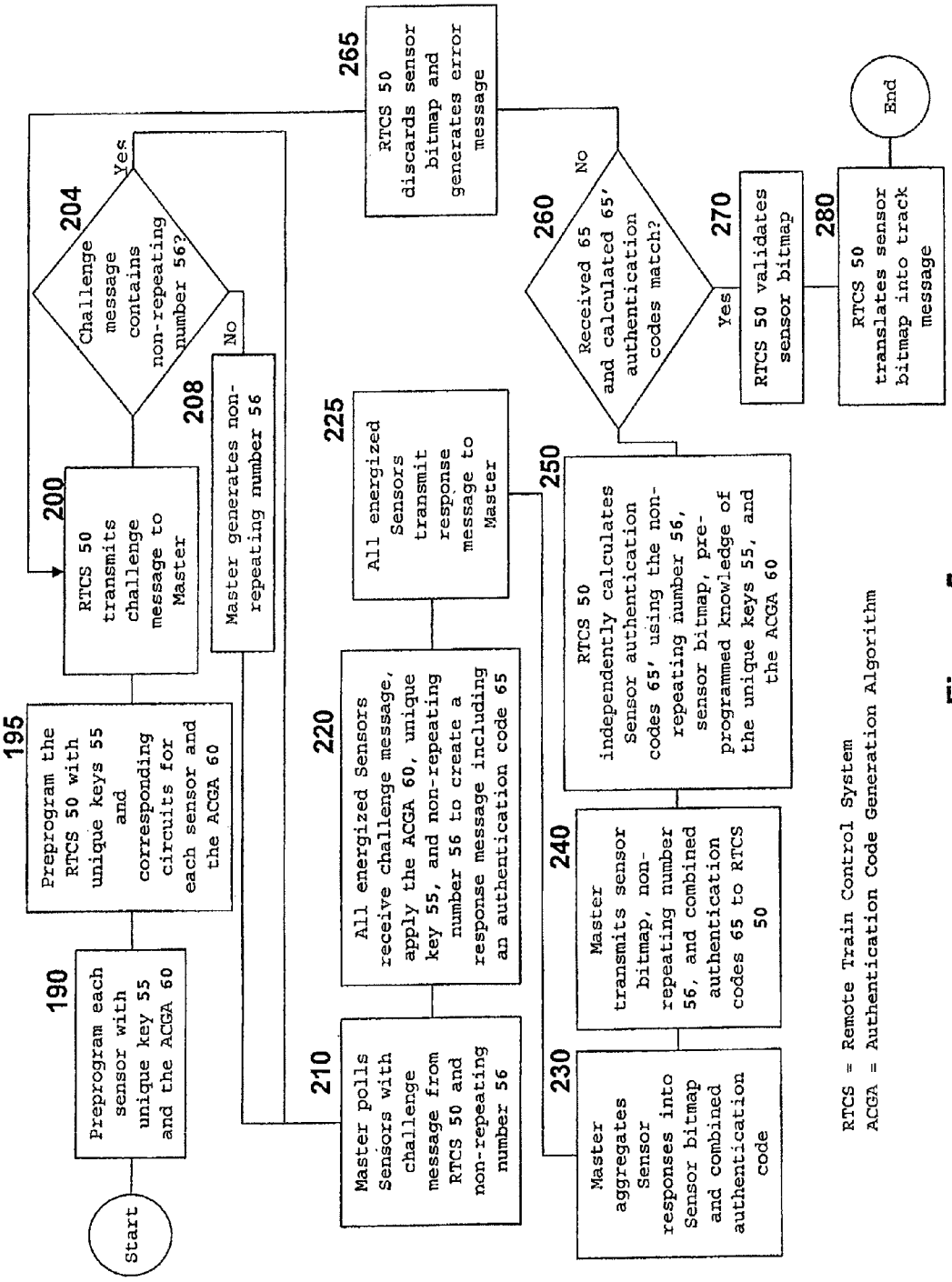

Start
90
Preprogram each sensor with unique key 55 and the ACGA 60
95
Preprogram the RTCS 50 with unique keys 55 and corresponding circuits for each sensor and the ACGA 60
100
RTCS 50 transmits challenge message to Sensor
110
Sensor Energized?
No
Yes
111
Challenge message contains non-repeating number 56?
No
Yes
112
Sensor generates non-repeating number 56
113
Sensor applies the ACGA 60, and unique key 55, and a non-repeating number 56 to create a response message including an authentication code 65
115
Sensor transmits response message (including authentication code 65) to RTCS 50
120
RTCS 50 independently calculates Sensor authentication code 65' using the non-repeating number 56, pre-programmed knowledge of the unique key 55, and the ACGA 60
130
Received 65 and calculated 65' authentication codes match?
No
Yes
140
RTCS 50 discards sensor response and generates error message
150
RTCS 50 validates sensor
160
RTCS 50 translates sensor into track message
End
RTCS = Remote Train Control System
ACGA = Authentication Code Generation Algorithm

Figure 4



RTCS = Remote Train Control System
ACGA = Authentication Code Generation Algorithm

Figure 5

RAILROAD SIGNALING AND COMMUNICATION SYSTEM USING A FAIL-SAFE VOLTAGE SENSOR TO VERIFY TRACKSIDE CONDITIONS IN SAFETY-CRITICAL RAILROAD APPLICATIONS

RELATED APPLICATIONS

This continuation application claims priority to and benefit from U.S. patent application Ser. No. 12/620,942, filed on Nov. 18, 2009, which is incorporated herein by reference.

STATEMENT REGARDING SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

REFERENCE TO A MICROFICHE APPENDIX

Not applicable.

FIELD OF THE INVENTION

The present invention relates to railroad signaling and communication. More specifically, the present invention relates to a fail-safe verification system and method for providing trackside conditions to a remote train control system, located on a locomotive or at a central office, to monitor visual signals or switch positions as used by the train engineer. Trackside conditions are monitored by sensing the voltage between railroad interlockings and trackside signaling electrical components which the interlocking uses to determine the track status and authorize train movement.

BACKGROUND OF THE INVENTION

Rail systems utilize the same tracks for two way traffic. Trackside signals indicating various track conditions are used by engineers, dispatchers, and computerized control systems to control access to the tracks and prevent conflicting train movements. Switches placed throughout the rail system divert traffic from the main track to side tracks (sidings) allowing trains to pass one another or to change the train's route. Switches are also utilized in rail yards to change the train's route. At the switch, the rails of the track are mechanically moved to successfully divert the train to the new track. The locomotive engineer visually monitors track signals located trackside to determine the status of the track switches and to obtain authority to enter a specific track section and takes action, for instance adjusting the speed of the train when signals indicate the train will be diverted to a siding due to switch positions. Since safety-critical decisions are made based on the status of the switches and signals, a system and method are needed to ensure that any signal and switch status is reported correctly. Due to the potential for operator error, it is beneficial for railroads to electronically verify the status of switches and signals along the track by communicating the status of these signals to a system on-board the locomotive. Based on the information received, the on-board system can monitor the speed and location of the train and override the engineer by, for example, applying the brakes if the train's authorized speed profile is in danger of being exceeded. Those of skill in the art will recognize that this system of electronically monitoring and controlling train movements to provide increased rail safety is commonly referred to as Positive Train Control.

Railroad signaling systems include complex interlockings which are arrangements of signaling apparatus (e.g. relays, software logic, etc.) that prevent conflicting train movements through an arrangement of tracks. By way of example, some of the fundamental principles of interlocking include: signals may not be operated to permit conflicting train movements to take place at the same time; switches in a route must be properly 'set' (in position) before a signal may allow train movements to enter that route; once a route is set and a train is given a signal to proceed over that route, all switches in the route are locked in position until either the train passes out of the portion of the route affected, or the signal to proceed is withdrawn and sufficient time has passed to ensure that a train approaching that signal has had opportunity to come to a stop before passing the signal. Interlockings can be categorized as mechanical, electrical (relay-based), or electronic (software-based).

Trackside input electrical components such as switch contacts and hazard detectors are electrically connected to the interlocking and provide track condition information as inputs to the interlocking. When the input electrical component needs to provide an input to the interlocking, voltage is applied to the connection or a contact closes a circuit, thereby sending a track condition input to the interlocking. The interlocking processes the multiple track condition inputs it receives and determines track status. The interlocking is electrically connected to output electrical components such as signals. The interlocking identifies the output electrical components to be energized based on the track status, and applies voltage to the connection between the interlocking and the particular output electrical components.

The prior art verification system for reporting the status of switches and signals to a remote train control system to confirm visual signals comprises a trackside central control unit with its own independent power supply and microprocessor. The central control unit is electrically connected via wiring or some similar physical method to each of a plurality of trackside electrical components, and can sense a combination of electrical voltages and currents in these components. The microprocessor of the central control unit continuously monitors the electrical components to measure their electric current and/or voltage and determines track conditions such as which signal lamps are on, the positions of switches, and the state of any other hazard detectors. It is critical in the prior art system that these electric measurements are correct. There are many outside influences such as lightning strikes, electrical surges, etc., that could affect the accuracy of the electric measurements. For this reason, the central control unit includes many additional, and often redundant, components such as duplicate sensors, multi-path processors, redundant input circuits and board, dual processing boards and additional software to ensure the accuracy of the electric readings. These prior art central control units are expensive due, in large part, to the additional components and software needed to ensure the accuracy of the electric readings.

One disadvantage of the prior art system is that it requires expensive, safety-validated software for the microprocessor and significant testing to ensure that all failure modes have been addressed. Maintaining such a software development process for the lifetime of the product burdens it with significant cost. A second disadvantage of the existing system is that the microprocessor is centrally mounted in a trackside bungalow, and a significant amount of wiring is

needed to reach the various sensing points. This adds cost to the deployment into existing bungalows.

It is an objective of the present invention to provide a fail safe voltage sensor for verifying the status of trackside signals and switches in safety-critical railroad applications which eliminates the need for duplicative components to account for all potential errors and failures. Another objective of the present invention is to provide a cost effective, single input sensor to replace more expensive, multi-input equipment used in prior art systems. Another objective of the present invention is to provide a sensor with low power consumption which allows for longer battery life of the overall trackside control system. The trackside installations including the trackside signals and switches, the interlocking, the central control unit and other components are typically powered by a bank of batteries located at the trackside installation. Yet another objective is to provide a voltage sensor which can be installed near to each electrical component to be sensed thereby greatly reducing the amount of wiring needed to connect the prior art multi-input systems to each electrical component and the cost of installing and testing these large lengths of wire.

SUMMARY OF THE INVENTION

The system comprises at least one microprocessor-based voltage sensor for providing trackside conditions to a remote train control system which controls train movement. The sensor is electrically connected to a trackside circuit for providing trackside conditions to a railroad interlocking. The trackside circuit further comprises a trackside signaling electrical component and an interlocking Examples of trackside signaling electrical components which may be included in the trackside circuit are switch contacts, hazard detectors, such as snow and flood detectors, and signal lamps, but those of skill in the art will recognize that there are many trackside signaling electrical components which may be employed. In one embodiment, the sensor is electrically connected to the circuit between the electrical component (input electrical component) and the input of the interlocking. When the input electrical component closes the circuit via electrical contact or applies voltage across the circuit, voltage is also applied across the sensor. In another embodiment, the sensor is electrically connected to the circuit at the output of the interlocking and the input of the electrical component (output electrical component). When the interlocking applies voltage to the circuit to power the output electrical component, voltage is also applied to the sensor. The sensor does not have an independent power supply and, because the sensor is electrically connected to the circuit, the sensor is powered by the voltage present in the energized circuit.

The sensor is capable of two-way electronic communication with a remote train control system, for example a remote computer system located on-board a locomotive or in a centralized office. The remote train control system is used to control train movement. Because the sensor is powered solely by the voltage of the energized circuit that it is connected to, i.e. the same voltage powering the visual signal or, in a case of a trackside switch, the voltage controlled by the contacts in the track switch enclosure, the sensor cannot transmit a message unless the circuit is energized, thereby eliminating the chance of false messages. The remote train control system uses the sensor status information to determine track status and control the movement of the locomotive. It is critical that the information on track status be accurate; therefore, the elimination of false messages from the verification system is very beneficial.

In one embodiment the electronic communication means is a wireless communication means. Such wireless communication galvanically isolates the input sensors from each other and from the other electrical components. Because the sensors are electrically isolated, the chance of undesirable short-circuits allowing energy from one circuit to feed into another is eliminated.

In another embodiment, the system further comprises a trackside master microprocessor capable of two way communication with multiple sensors and with the train control system. In this embodiment, all the sensors communicate with a single master microprocessor. The master microprocessor compiles all messages received from the various sensors into a single, aggregate message which it transmits to the remote train control system. Likewise, the remote train control system transmits messages which are received by the master microprocessor.

To protect the system from corrupted messages or messages from the wrong source reaching the remote train control system, each sensor in the system of the present invention is programmed and configured with a unique key and an authentication code generation algorithm (not unique). The remote train control system is pre-programmed with knowledge of the trackside circuit to which each sensor is connected, the unique key identifying each individual sensor and the authentication code generation algorithm. To verify track status for use in controlling train movement, the remote train control system will transmit a challenge message requesting sensor status. All energized sensors will receive the challenge message and each sensor will generate a unique authentication code, utilizing the sensor's unique key and then transmit the authentication code to the remote train control system. The remote train control system validates the received message by independently generating the authentication code for each sensor using a priori knowledge of each sensor's unique key. The remote train control system compares the received authentication codes with its independently generated authentication codes to validate the message. If the received authentication code matches the independently generated authentication code, the remote train control system validates the message and accepts that the sensors that reported are indeed active. The remote train control system associates the active sensors with the circuits using the pre-programmed knowledge of which sensors are connected with particular circuits in the remote train control system and confirms the track conditions based on which sensors are active. The remote train control system makes other decisions regarding train movement based on the verified track conditions.

Those of skill in the art will recognize that many different authentication code generation technologies could be used to create authentication codes and many different transmission schemes could be employed to transmit the authentication codes from the sensors to the remote train control system. In one embodiment, each sensor is pre-programmed and configured with a unique private key and a Hashed Message Authentication Code (HMAC) algorithm. The remote train control system is pre-programmed with knowledge of the circuit to which each sensor is connected, a unique key for each sensor and the HMAC algorithm. To verify track status, the remote train control system will transmit a challenge message requesting sensor status. All energized sensors will receive the challenge message and generate an HMAC code unique to the particular sensor using the unique key and HMAC algorithm, then transmit the HMAC code to the remote train control system. The remote train control system validates the received HMAC codes using the pre-pro-

grammed unique keys and the HMAC algorithm. If the HMAC code is valid, the remote train control system is able to confirm the track conditions based on which sensors are energized.

In another embodiment, each sensor communicates with a master microprocessor. The authentication code validation technology, such as an HMAC algorithm, is not programmed into the master microprocessor and the master microprocessor is not capable of authenticating the messages from the sensors. The remote train control system transmits a challenge message requesting sensor status to the trackside master microprocessor which in turn transmits a challenge message requesting sensor status to multiple sensors. Any energized sensors receive the challenge message from the trackside master microprocessor and generate an authentication code unique to the particular sensor. The energized sensors transmit their authentication codes to the master microprocessor. The master microprocessor compiles all authentication codes received from the various sensors into an aggregate authentication message which it transmits to the remote train control system. The master microprocessor is not programmed to authenticate the sensor messages. The trackside master microprocessor merely forwards the authentication codes to the remote train control system. The remote train control system validates the aggregate authentication code message using the pre-programmed unique keys and the authentication code generation algorithm. If the authentication code is valid, the remote train control system is able to confirm the track conditions based on which sensors are energized and use this information to control train movement.

For example, in one embodiment, the energized sensors generate a HMAC unique to the particular sensor using the sensor's unique key and the HMAC generation algorithm. The energized sensors transmit the HMAC to the trackside master microprocessor. The trackside master microprocessor compiles all HMACs received from the various sensors into a single, aggregate authentication message which it transmits to the remote train control system. The remote train control system validates the received HMAC by comparing the received codes to its independently generated HMAC created using the unique keys of the reporting sensors and the HMAC generation algorithm. If the received HMAC matches the remote train control system's independently generated HMAC, then the remote train control system accepts the validity of the active sensors reporting and correlates the active sensors and sensor locations to confirm the track status.

In an alternative embodiment, the sensors are arranged into clusters such that each cluster is related to a specific train route. For example, a certain section of track may have a first cluster of sensors for eastbound movement and a second cluster of sensors for westbound movement. Each cluster has a trackside master microprocessor pre-programmed with the number of sensors in its cluster. The master microprocessor in the cluster sequentially polls each sensor in its cluster when it receives a challenge message from the remote train control system. The master microprocessor reports aggregate authentication codes to the remote train control system. Since all sensors across all clusters have globally unique keys, the remote train control system may use the pre-programmed sensor key and sensor location information to validate sensors in the same cluster or across multiple clusters.

Utilizing the master microprocessor to transmit an aggregate message to the remote train control system is beneficial because it reduces the bandwidth used without sacrificing data security. System security is maintained even with the introduction of the additional trackside master microprocessor because the master microprocessor cannot generate any valid authentication codes.

In another embodiment, each authentication code generated by each sensor takes, as input to the authentication code generation algorithm, a non-repeating number such as a time stamp, to protect against stale messages that might reach the remote train control system. When the remote train control system receives the authentication code, it validates the authentication code using both the sensor's unique key and the non-repeating number. If the non-repeating number is timely, the authentication code is validated. If the non-repeating number is not timely, the authentication code is discarded and the remote train control system sends another challenge message requesting sensor status.

The verification system and method of the present invention allows cost effective, single-chip microprocessors to be deployed as single input (single bit) fail-safe voltage sensors, replacing more expensive, multi-input prior art sensing equipment. Each sensor of the present invention is located near the electrical component it is sensing, thus obviating the need for wiring between each sensing point and a central communications controller as in the prior art equipment. The single-chip, single input arrangement of microprocessors as a fail-safe voltage sensor provides: protection against false reporting of a trackside circuit status (energized vs. non-energized), fast cycle time from application of power to the sensor to the reporting of energized status, flexible arrangement of multiple sensors into clusters for combining status messages reporting; and low power consumption and control over external communications devices to manage sleep-mode mechanisms for longer battery life at trackside installations which is particularly important at solar powered installations, and in embodiments utilizing wireless communications means, galvanic isolation of the input to be monitored from other circuits and power sources.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an illustration showing the components of the railroad signaling and communication system for verifying trackside conditions of the present invention as interconnected to an interlocking attached to a track circuit.

FIG. **2** is an illustration showing the components of the railroad signaling and communication system for verifying trackside conditions of the present invention at a single trackside installation in communication with the remote train control system.

FIG. **3** is an illustration showing the components of the railroad signaling and communication system for verifying trackside conditions of the present invention at multiple trackside installations in communication with the remote train control system.

FIG. **4** is a flowchart representing the steps performed by the railroad signaling and communication system for verifying trackside conditions of the present invention in an embodiment without a master microprocessor.

FIG. **5** is a flowchart representing the steps performed by the railroad signaling and communication system for verifying trackside conditions of the present invention in an embodiment with a master microprocessor.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. **1**, the verification system **3** of the present invention comprises at least one voltage sensor **1** for

providing trackside conditions to a remote train control system **50** (see FIG. **2**) electrically connected to a trackside circuit for providing trackside conditions to a railroad interlocking **2**, said circuit comprising a power supply **4**, an interlocking **2**, and a trackside signaling electrical component **10**. Each of the at least one sensors **1** corresponds to a different electrical component **10**. A plurality of sensors **1** and electrical components **10** may be electrically connected to the same railroad interlocking **2** and power supply **4** creating a plurality of circuits. The voltage sensor **1** is powered by the voltage from the circuit and has no independent power supply; therefore, it is energized only when the electrical component **10** is engaged and the circuit is energized. In one embodiment, the trackside signaling electrical component **10** is an input electrical component **11** connected to an input of the interlocking **2**. Those of skill in the art will recognize that there are many types of input electrical components **11** utilized in a railroad signaling system which provide inputs to an interlocking, for example, relays, switch contacts and hazard detectors (e.g. snow detectors, avalanche detectors, high water detectors, broken track detectors, etc.). The input electrical component **11** is electrically connected to interlocking **2** creating input circuit **6**. In a circuit, a node is a place where circuit elements are connected to one another. The input circuit **6** has at least three nodes: A, B, and C. The input electrical component **11** is positioned between nodes A and B; the sensor **1** is positioned between nodes B and C; the interlocking **2** is positioned between nodes A, B, and C; the power supply **4** is positioned between nodes A and C. A positive terminal of the power supply **4** is adjacent to node A and a negative terminal of the power supply **4** is positioned adjacent to node C. When the input electrical component **11** is engaged (switch contact is connected, hazard detector is engaged, etc.), voltage is applied to input circuit **6**, input circuit **6** and voltage sensor **1** are energized, and input electrical component **11** provides an input to interlocking **2**. The input correlates to a certain track condition (switch in position, broken track, train present, etc.).

In another embodiment, the electrical component **10** is an output electrical component **12** which is electrically connected to an output of the interlocking **2**. Those of skill in the art will recognize that there are many types of output electrical components **12** utilized in a railroad signaling system which receive outputs from an interlocking, for example, signals. Interlocking **2** is electrically connected to the output electrical component **12** creating output circuit **7**. In a circuit, a node is place where circuit elements are connected to one another. The output circuit **7** has at least four nodes: A, C, D, and E. The interlocking **2** is positioned between nodes A, C, D, and E. The sensor is positioned between nodes D and E. The output electrical component **12** is positioned between nodes D and E. The power supply **4** is positioned between nodes A and C. A positive terminal of the power supply **4** is adjacent to node A and a negative terminal of said power supply **4** is adjacent to node C. The interlocking **2** determines the track status based on received inputs and, based on that status, the output to send to the output electrical component **12**, for example authorizing entry to a certain track section, alerting the engineer that a switch is in the position for a siding, warning of high water on the track and prohibiting entry to a certain track section, indicating a reduced speed limit, etc.

In yet another embodiment, the interlocking **2** is electrically connected to at least one input electrical component **11** creating an input circuit **6** and at least one output electrical component **12** creating an output circuit **7**.

Those of skill in the art will recognize that the power supply **4** can be any D.C. power supply, for example a battery or bank of batteries. The sensor **1** for providing trackside conditions to a remote train control system **50** has a low power, single-chip microprocessor. The present invention allows cost effective single-chip microprocessors to be used as single input (single bit) fail-safe voltage sensors, replacing the more expensive, multi-input equipment used in prior art systems. Because the sensor **1** and the trackside signaling electrical component **10** of the system of the present invention are both powered by the voltage from the energized circuit for providing trackside conditions to the railroad interlocking **2**, it is important that the sensor **1** uses a low amount of power and draws as little current from the circuit as possible so that there is enough current remaining to power the trackside signaling electrical component **10**. Those of skill in the art will recognize that there are many suitable low power microprocessors. For example, a Texas Instruments CC1110 Microprocessor that at peak operating conditions consumes 50 milliamps or less of the current flowing through the energized circuit may be used.

Referring now to FIG. **2**, the remote train control system **50** comprises a server and a database that act in a fail-safe (vital) manner to interpret the messages coming from the verification system **3** of the present invention. The verification system **3** reports the status of various sensors **1** (energized or de-energized). The server of the remote train control system **50** looks up the sensors **1** in the database and translates the status messages into actual rail information based on pre-programmed information. For example, a first sensor energized and a second sensor de-energized may mean that the switch is in the normal position. The remote train control system **50** then reports to the locomotive control system **51** the status of the electrical components **10** (e.g. that the switch is normal) using a different protocol. In one embodiment, the remote train control system **50** is located at a central office **52** and the central office server interprets the sensor status messages and sends translated control messages to the locomotive control system **51**. In another embodiment, the remote train control system **50** is on-board the locomotive and the locomotive control system **51** receives the sensor status messages directly and interprets them.

The sensor **1** has an electronic communication means **18**, and is capable of two-way electronic communication with a remote train control system **50** for controlling train movement, for example a system located on-board a locomotive **51** or in a centralized office **52**. Because the sensor **1** for providing trackside conditions to the remote train control system **50** is powered solely by the voltage of the energized trackside circuit for providing trackside conditions to the railroad interlocking **2**, the same voltage powering the trackside signaling electrical component **10**, the sensor **1** cannot transmit a message unless the circuit is energized thereby eliminating the chance of false messages. The remote train control system **50** uses the sensor status information to verify visual signals and critical track conditions (switch contact energized, snow melter energized, signal authorizing entry to certain track, etc.) based on the status of the electrical components **10** which are used by the interlocking **2** to determine track status. The train engineer or remote train control system **50** ultimately uses the track status to control the movement of the locomotive; therefore, it is critical that the track condition information be accurate. The elimination of false messages from the verification system is very beneficial.

Those of skill in the art will recognize that there are many means of two-way electronic communication which can be utilized such as via serial port or by wireless communication means. Embodiments where wireless communication is used are beneficial because wireless communication galvanically isolates the sensors **1** from each other and from the other electrical components **10**. Because the sensors **1** are electrically isolated, the chance of creating undesirable short-circuit paths allowing energy from one circuit to feed into another is eliminated.

One advantage of the verification system of the present invention is that it reduces the complexity of the equipment in comparison with prior art verification systems. Each single input microprocessor based voltage sensor **1** can be located in close proximity to the electrical component **10** output it is sensing. For example, the sensor **1** may be electrically connected to the electrical component **10** by a bracket or a short wire. The prior art, multi-input systems require long lengths of wire between the centrally located microprocessor and the electrical components which adds installation and maintenance costs to the prior art systems. An additional advantage of the present invention is that the low power consumption of each single input microprocessor based voltage sensor **1** provides for longer battery life at the trackside installation which is particularly helpful at solar powered installations. In some embodiments, the electronic communication means **18** has a transmitter and a receiver (not shown). The sensor microprocessor may be programmed to only power up the transmitter when it is sending a message thereby further reducing the power consumption of the verification system **3** and conserving battery life at the trackside installation.

Still referring to FIG. **2**, in another embodiment, the system **3** further comprises a trackside master microprocessor **30** having a means for two way electronic communication **25** and capable of two way communication with both the sensors **1** and the remote train control system **50**. Those of skill in the art will recognize that there are many suitable microprocessors which can be utilized as the master microprocessor **30** of the present invention. In some embodiments, a low power microprocessor is used as the master microprocessor **30**. For example, a Texas Instruments CC1110 Microprocessor that at peak operating conditions consumes 50 milliamps or less of current can be used. It is beneficial to use a low power microprocessor in some embodiments to conserve battery life of the overall control system at the trackside installation. This is particularly beneficial at solar powered installations. The assigned sensors **1** and master microprocessor **30** are capable of two-way communication. The master microprocessor **30** compiles all messages received from the various sensors **1** into a single, aggregate authentication message which it transmits to the remote train control system **50**. Likewise, the remote train control system **50** transmits messages to the master microprocessor **30**. Those of skill in the art will recognize that there are many means of two-way electronic communication which can be utilized such as via serial port or by wireless communication means.

In some embodiments, the electronic communication means **25** of the master microprocessor has a transmitter and a receiver (not shown). The master microprocessor **30** may be programmed to only power up the transmitter when it is sending a message thereby further reducing the power consumption of the verification system and conserving battery life at the trackside installation.

Referring now to FIG. **3**, in some embodiments a cluster **40** of sensors **1** located in a particular trackside installation is assigned to a particular master microprocessor **30** also located at the trackside installation as shown in FIG. **3**. The remote train control system **50** is pre-programmed to communicate with a particular master microprocessor **30** and cluster **40** at different times based on the locomotive's position and route. The present invention discloses an improved method for verifying track conditions in safety critical railroad applications by reporting the status of track-side signals and switches to a remote train control system to confirm visual signals and control train movement using the system **3** disclosed herein. The remote train control system **50** verifies the track status along the route of a particular locomotive by requesting and verifying the status of a certain sensor or sensors **1** located on its route.

Referring now to FIG. **4**, each sensor **1** is pre-programmed with a unique key **55** and an authentication code generation algorithm **60**. The remote train control system **50** is pre-programmed with knowledge of the unique keys **55** for and the corresponding circuits to which each of the sensors **1** are connected and the authentication code generation algorithm **60**. To verify track status, the remote train control system **50** transmits a challenge message requesting sensor status to a particular sensor **1** on its route (**100**). If the sensor **1** is energized (**110**), the sensor **1** uses its unique key **55** as an input to the authentication code generation algorithm **60**, thereby creating a response message (**113**) including an authentication code **65**. The sensor **1** transmits the response message (**115**) to the remote train control system **50**. In one embodiment, the authentication code generation algorithm **60** requires two pieces of information to generate an authentication code **65**: the unique key **55** for the particular sensor **1** and a non-repeating number **56** such as a time stamp. Upon receipt of the challenge message, the energized sensor **1** uses its unique key **55** and the non-repeating number **56** as inputs to the authentication code generation algorithm **60**, thereby creating a response message (**113**). The non-repeating number **56** may be provided by either the remote train control system **50** or the sensor **1** (**112**). If the non-repeating number **56** is provided by the remote train control system **50**, the non-repeating number **56** is transmitted to the sensor as part of the challenge message (**100**). If the non-repeating number **56** is provided by the sensor **1**, the non-repeating number **56** is transmitted to the remote train control system **50** as part of the response message (**115**).

The remote train control system **50** independently calculates an authentication code **65'** for the requested sensor **1** using a priori knowledge of the authentication code generation algorithm **60** and the unique key **55** for the particular sensor **1** located on the chosen route (**120**). The remote train control system **50** compares the calculated authentication code **65'** to the received authentication code **65** to determine if they match (**130**). If the calculated **65'** and received **65** authentication codes match, the remote train control system **50** validates the received sensor (**150**), and translates the received sensor into a track status message **160**, such as switch in normal position or track available, for utilization by the locomotive engineer or electronic control system to control the movement of the locomotive. If the calculated **65'** and received **65** codes do not match, the remote train control system **50** discards the response message and generates an error message (**140**). The error message may trigger another challenge message.

The unique key **55** and authentication code generation algorithm **60** provide a means for the remote train control system to identify corrupted messages and messages from the wrong source. Additionally, the use of a non-repeating

number **56** with the unique key **55** and authentication code generation algorithm **60** provides a means for the remote train control system to identify stale messages.

Those of skill in the art will recognize that many different authentication code generation technologies could be used to create authentication codes and many different transmission schemes could be employed to transmit the authentication codes **65** from the sensors **1** to the remote computer process **50**. In one embodiment, the authentication code generation algorithm **60** is a Hashed Message Authentication Code (HMAC). Each sensor **1** is programmed and configured with a unique key **55** and the HMAC algorithm. The remote train control system **50** is pre-programmed with knowledge of the circuit connected to each sensor **1**, a unique key **55** for each sensor **1** and the HMAC algorithm. Upon receipt of a challenge message from the remote train control system **50**, the energized sensor (**110**) applies the HMAC algorithm to the unique key **55** and, in some embodiments, the non-repeating number **56** generated either by the remote train control system **50** or the sensor **1** to produce a HMAC (**113**). The sensor **1** transmits the HMAC to the remote train control system **50** as part of the response message (**115**).

The remote train control system **50** independently calculates the HMAC for the requested sensor **1** using the a priori knowledge of the HMAC algorithm, in some embodiments the non-repeating number **56**, and the unique key **55** for the particular sensor **1** located on the chosen route (**120**). In another embodiment, a trackside master microprocessor **30** is used as shown in FIG. **2**. The master microprocessor **30** is in two-way communication with the sensors **1** and with the remote train control system **50**. In some embodiments utilizing a master microprocessor **30** as shown in FIG. **3**, a group or cluster **40** of sensors **1** is assigned to a particular master microprocessor **30**. For example, a cluster **40** may be comprised of all the sensors **1** at a particular trackside installation and assigned to a master microprocessor **30** at that particular trackside installation. Each sensor **1** in the cluster **40** communicates with the particular master microprocessor **30** assigned to its cluster **40**. Since all sensors **1** across all clusters **40** have globally unique identifiers (unique keys **55**), the remote train control system **50** may use the preprogrammed sensor key **55** and corresponding circuit associated with the sensor **1** to validate sensors **1** in the same cluster **40** or across multiple clusters **40**.

Referring now to FIG. **5**, the verification method may alternatively use a trackside master microprocessor **30**. In this embodiment, each sensor **1** for providing trackside conditions to a remote train control system **50** is pre-programmed with a unique key **55** and an authentication code generation algorithm **60**. The remote train control system **50** is pre-programmed with knowledge of the unique keys **55** and the corresponding circuits to which each of the sensors **1** are connected and the authentication code generation algorithm **60**. The authentication code generation algorithm **60**, such as the HMAC algorithm, is not programmed into the master microprocessor **30** and the master microprocessor **30** is not capable of authenticating the messages from the sensors **1**. The remote train control system **50** transmits a challenge message requesting sensor status to a particular master microprocessor **30** on a particular train's route **200**. The master microprocessor **30** sequentially polls each of the sensors **1** in communication with the master microprocessor **30** requesting sensor status (**210**). Each sensor **1** is pre-programmed with a unique key **55** and an authentication code generation algorithm **60**. The remote train control system **50** is preprogrammed with knowledge of at least one of the unique keys **55** and the corresponding circuit to which the at least one sensor **1** is connected and the authentication code generation algorithm **60**. If the sensor **1** is energized, the sensor **1** uses its unique key **55** as an input to the authentication code generation algorithm **60**, thereby creating a response message (**220**) including an authentication code **65**. The sensor **1** transmits the response message (**225**) to the master microprocessor **30**. The master microprocessor **30** combines the received sensor responses into an aggregate authentication message comprising a sensor bitmap and combined authentication code (**230**) and transmits the aggregate message (**240**) to the remote train control system **50**.

In another embodiment, to protect against stale messages, the authentication code generation algorithm requires two pieces of information to generate an authentication code: the unique key **55** for the particular sensor **1** and a non-repeating number **56** such as a time stamp. The non-repeating number **56** may be provided by either the remote train control system **50** or the master microprocessor **30** (not shown). If the non-repeating number **56** is provided by the remote train control system **50**, the non-repeating number **56** is transmitted to the master microprocessor **30** as part of the challenge message (**200**). If the non-repeating number **56** is provided by the master microprocessor **30**, the non-repeating number **56** is created (**208**) by the master microprocessor **30** upon receipt of the challenge message and transmitted to the sensors **1** during polling (**210**). The polling message includes both a request for status and a non-repeating number **56**. If the sensor **1** is energized, upon receiving the polling message from the master microprocessor **30**, the sensor **1** applies the authentication code generation algorithm **60** to the polling message thereby creating a response message (**220**). The sensor **1** transmits the response message (**225**) to the master microprocessor **30**. The master microprocessor **30** combines the received sensor responses into an aggregate authentication message comprising a sensor bitmap, combined authentication code **65**, and the non-repeating number **56** (**230**) and transmits the aggregate message (**240**) to the remote train control system **50**.

The remote train control system **50** independently calculates the sensor authentication codes **65'** for the sensors **1** in the requested cluster **40** using the prior knowledge of the authentication code generation algorithm **60**, the unique keys **55** for the particular sensors **1** located in the cluster **40** on the chosen route, and, in some embodiments, also uses the non-repeating number **65** (**250**). The remote train control system **50** compares the calculated authentication code **65'** to the received authentication codes **65** to determine if they match (**260**). If the calculated authentication code **65'** and received authentication code **65** match, the remote train control system **50** validates the received sensor bitmap (**270**) and translates the received sensor bitmap into a track status message based on which sensors are energized (**280**), such as switch in normal position or track available, for utilization by the locomotive engineer or electronic control system to control the movement of the locomotive. If the calculated **65'** and received **65** codes do not match, the remote train control system **50** discards the response message and generates an error message (**265**). The error message may trigger another challenge message.

Those of skill in the art will recognize that many different authentication code generation technologies could be used to create authentication codes **65** and many different transmission schemes could be employed to transmit the authentication codes **65** from the sensors to the remote train control system **50**. In one embodiment, each sensor is programmed and configured with a unique private key **55** and a Hashed Message Authentication Code (HMAC) algorithm **61**. The

remote train control system **50** is pre-programmed with knowledge of the circuit to which each sensor is electrically connected, a unique key **55** for each sensor and the HMAC algorithm **61**.

Utilizing a master microprocessor **30** to transmit an aggregate message to the remote train control system is beneficial because it reduces the bandwidth used without sacrificing data security. System security is maintained even with the introduction of the master microprocessor **30** because the master microprocessor **30** cannot generate any valid authentication codes.

Thus, it is seen that the method and system for verifying the status of trackside signals and switches in safety critical railroad applications of the present invention readily achieves the ends and advantages mentioned as well as those inherent therein. While certain preferred embodiments of the invention have been illustrated and described for the purposes of the present disclosure, it is recognized that these embodiments are not intended to be limiting, and that departures may be made therefrom within the scope of the invention and that numerous modifications may be made by those skilled in the art, which changes are encompassed within the scope and spirit of the present invention as defined by the following claims.

We claim:

1. A railroad signaling and communication method for verifying trackside conditions which are used to control train movement in safety critical railroad applications comprising:

pre-programming at least one sensor for providing trackside conditions to a remote train control system with a unique key and an authentication code generation algorithm;

electrically connecting each sensor to a trackside electrical circuit for providing trackside conditions to a railroad interlocking associated with a trackside signaling electrical component, said circuit including the electrical component and the railroad interlocking, said sensor positioned electrically intermediate to said electrical component and said interlocking;

powering said sensor by voltage applied to said circuit such that said sensor is energized only when said electrical component is engaged;

pre-programming a remote train control system for verifying the status of trackside electrical components indicating track conditions with the unique key assigned to each of the at least one sensors, an identification for the electrical circuit which each of the at least one sensors is connected, and the authentication code generation algorithm;

requesting sensor status by transmitting a challenge message from a remote train control system which is received by energized sensors; generating an authentication code, in each of the energized sensors, using the unique key for that sensor and authentication code generation algorithm;

creating a response message from each energized sensor containing the authentication code;

transmitting the response message from each energized sensor to the remote train control system;

independently calculating, in the remote train control system, a calculated authentication code for each of the sensors along a particular route using the unique keys, circuit identification, and authentication code generation algorithm pre-programmed into the remote train control system;

validating the response message by matching the calculated authentication codes to the received authentication codes; and translating the validated response message into a track status message.

2. The railroad signaling and communication method of claim **1** further comprising:

generating a non-repeating number for use with the authentication code generation algorithm;

utilizing both the non-repeating number and the unique key for the sensor as inputs to the authentication code generation algorithm to generate the authentication code for the response message in each energized sensor; and

utilizing both the non-repeating number, the unique key and the circuit identification for each sensor along a particular route as inputs to the authentication code generation algorithm to independently calculate the calculated authentication code in the remote train control system.

3. The railroad signaling and communication method of claim **2** wherein:

the non-repeating number is generated by the remote train control system and transmitted to the energized sensors as part of the challenge message.

4. The railroad signaling and communication method of claim **2** wherein:

the non-repeating number is a time stamp.

5. The railroad signaling and communication method of claim **1** further comprising:

assigning at least two sensors to a master microprocessor creating a cluster of sensors;

transmitting the challenge message from the remote train control system to a master microprocessor;

transmitting the challenge message to each energized sensor by having the master microprocessor sequentially poll each sensor in the cluster;

transmitting the response message from each energized sensor to the master microprocessor;

aggregating the response messages into an aggregate authentication message in the master microprocessor;

transmitting the aggregate authentication message from the master microprocessor to the remote train control system;

validating aggregate authentication message by matching the calculated authentication codes to the authentication codes in the aggregate message; and

translating the validated aggregate authentication message into a track status message.

6. The railroad signaling and communication method of claim **5** further comprising:

generating a non-repeating number for use with the authentication code generation algorithm;

utilizing both the non-repeating number and the unique key for the sensor as inputs to the authentication code generation algorithm to generate the authentication code for the response message in each energized sensor; and

utilizing both the non-repeating number, the unique key and the circuit identification for each sensor in a cluster as inputs to the authentication code generation algorithm to independently calculate the calculated authentication code in the remote train control system.

7. The railroad signaling and communication method of claim **6** further comprising:

generating the non-repeating number in the remote train control system and transmitting the non-repeating number to the master microprocessor as part of the challenge message; and

transmitting the non-repeating number from the master microprocessor to each sensor as part of the challenge message during polling.

8. The railroad signaling and communication method of claim **6** further comprising:

generating the non-repeating number in the master microprocessor and transmitting the non-repeating number to each sensor as part of the challenge message during polling; and

transmitting the non-repeating number from the master microprocessor to the remote train control system as part of the aggregate authentication message.

9. The railroad signaling and communication method of claim **6** wherein:

the non-repeating number is a time stamp.

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